ANNALS OF SURGERY
Vol. 237, No. 4, 509–514

Effect of Hospital Volume and Experience on In-Hospital Mortality for Pancreaticoduodenectomy

Vivian Ho, PhD,* and Martin J. Heslin, MD†

*From the *Department of Health Care Organization and Policy and the †Department of Surgery, University of Alabama Birmingham, Birmingham, Alabama*

Objective
To examine the relative impact of procedure volume versus years of hospital experience on inpatient death rates after pancreaticoduodenectomy.

Summary Background Data
Past studies have identified a significant volume–outcome relation for hospitals performing pancreaticoduodenectomy (the Whipple procedure).

Methods
Administrative discharge data were examined for 6,652 patients who underwent the procedure between 1988 and 1998 in California and Florida. Patients were divided into approximate quartiles according to each hospital's annual procedure volume: very low (1), low (2 or 3), medium (4–9), and high (10+). Logistic regression analysis was used to examine differences in inpatient mortality among hospitals with different procedure volume and years of experience, while adjusting for patient characteristics.

Results
Medium- and high-volume hospitals had lower rates of inpatient mortality after pancreaticoduodenectomy relative to very-low-volume facilities. Greater years of hospital experience also reduced the odds of inpatient death. Predictions based on the regression estimates indicate that within volume categories, increased hospital experience did not lead to significant reductions in inpatient mortality. However, high-volume hospitals had significantly lower inpatient mortality rates than very-low-volume facilities with the same amount of experience.

Conclusions
Hospitals with more years of experience with pancreaticoduodenectomy had lower rates of inpatient mortality. However, higher procedure volume has played a larger role than increased experience in reducing inpatient death rates.

An association between high procedure volume and better patient outcomes has been identified for numerous surgical procedures.[1–5] The magnitude of the association between procedure volume and inpatient mortality is particularly high for patients undergoing pancreaticoduodenectomy (the Whipple procedure). Inpatient mortality rates for this procedure range by as much as fourfold between the lowest-volume and highest-volume hospitals in patient populations found in Maryland, New York, and the U.S. Medicare program.[6–9] Studies of the Whipple procedure and pancreatic resection offer compelling support for the volume–outcome hypothesis because of their size and the diversity of study designs.[10]

Less is known about the relation between years of operating experience and inpatient mortality for the Whipple procedure. Examination of other complex interventions reveals that outcomes for low-volume hospitals can improve over time, narrowing the disparity in patient outcomes by hospital volume.[11] The impact of hospital experience on outcomes is of interest, given that many low-volume hos-

Supported by a pilot project grant from the University of Alabama Birmingham Comprehensive Cancer Center.
Correspondence: Vivian Ho, PhD, Department of Health Care Organization and Policy, University of Alabama Birmingham, RPHB 330, 1665 University Blvd., Birmingham, AL 35294-0022.
E-mail: vho@uab.edu
Accepted for publication February 22, 2002.

pitals have been performing the Whipple procedure continuously for several years. This study examines the magnitude of the association between inpatient mortality with both hospital procedure volume and years of operating experience for the Whipple procedure.

METHODS

Patient data were obtained from statewide hospital discharge claims files for California and Florida for the years 1988 to 1998. A total of 6,709 patients who underwent the Whipple procedure (ICD-9-CM procedure code 52.7) were identified. Of these, 57 patients with an ICD-9-CM primary diagnosis code beginning with "8" were excluded. This general category represents admission due to injury and poisoning, and further examination of the primary and secondary diagnosis codes for these patients suggested that they were undergoing the Whipple procedure due to trauma.

The outcome variable of interest was inpatient mortality. The explanatory variable of interest was hospital procedure volume. For each hospital the total number of Whipple procedures in each calendar year was calculated. Hospitals were then classified into approximate volume quartiles based on the annual number of Whipple procedures performed. The volume cut-points were defined prospectively to avoid potential bias resulting from posthoc analysis.[8] Because many hospitals increased their procedure volume over time, some hospitals were classified into a lower-volume quartile for patients at the beginning of the sample but a higher-volume quartile for patients near the end of the sample.

The number of years of experience a hospital had with performing Whipple procedures was calculated as the number of years the hospital performed at least one Whipple procedure. Patient characteristics used as independent variables included age (<60, 60–69, 70–79, 80+), gender, and comorbidities. The component variables of the Charlson comorbidity index, which measures illness severity among patients, were included as explanatory variables. The variables were coded by the use of a methodology developed specifically for administrative data.[12] The two comorbidity categories specific to cancer (any malignancy and metastatic solid tumor) were excluded from the construction of the comorbidity index and the subsequent analysis.

Analysis

Descriptive statistics were used to characterize inpatient mortality and patient characteristics by hospital procedure volume. Mean values of age and the Charlson comorbidity index, the inpatient mortality rate, and the percentage of patients who were female or who had selected comorbidities were reported. Descriptive statistics were calculated by volume quartile and time period (1988–91, 1992–95, and 1996–98).

A logistic regression analysis was used to examine the association of inpatient mortality with both hospital procedure volume and years of experience, controlling for patient characteristics. All standard errors for regression estimates were derived accounting for potential correlation in unobserved treatment effects across patients treated by the same hospital.[13–15]

The logistic regression estimates were used to construct predicted inpatient mortality rates for increasing hospital size and experience categories. The characteristics of all sample patients treated in 1998 were used to derive these predictions. Predicted inpatient mortality rates for these patients were derived assuming they had been treated in a very-low/low-volume, medium-volume, or high-volume hospital with 7 years of experience. Predictions for each size category were also calculated assuming the hospital had 1, 4, or 11 years of experience performing the Whipple procedure. Predictions were calculated only for combinations of hospital volume and experience that were represented by at least one hospital in 1998. Mean predicted inpatient mortality rates and confidence intervals for all patients within each volume/experience combination were then calculated. All estimation was conducted using Stata 7.0.

RESULTS

The analysis was based on 6,652 admissions for patients who underwent the Whipple procedure between 1988 and 1998. The mean age was 63.6 years. Forty-seven percent were women. The mean of the Charlson comorbidity index was 2.9.

During the study period, 500 hospitals (334 in California, 166 in Florida) performed at least one Whipple procedure. In 1988, 224 hospitals performed the Whipple procedure, while 242 hospitals reported performing at least one procedure in 1998. A total of 92 hospitals (18%) performed the Whipple procedure in only 1 year during the sample period. By 1998, 80% of hospitals performing the Whipple procedure in that year had accumulated 5 or more years of experience. However, only 29 hospitals (6%) in the entire sample performed the Whipple procedure continuously from 1988 to 1998.

The number of procedures performed annually in each hospital ranged from 1 to 80. The median annual Whipple volume was two procedures in 1988 and rose to five procedures per year by 1998. During the sample period 18% of patients were treated in a very-low-volume hospital (1 procedure per year), 30% were treated in a low-volume hospital (2 or 3 procedures per year), 29% were treated in a medium-volume hospital (4–9 procedures per year), and 23% were treated in a high-volume facility (10+ procedures per year). By 1998, 10% of patients undergoing the Whipple procedure were still being treated in a hospital that performed only a single procedure that year.

The overall in-hospital mortality rate from 1988 to 1998 for patients who underwent the Whipple procedure was 9.5%. Table 1 lists information on mortality rates and pa-

Table 1. IN-HOSPITAL MORTALITY RATES AND PATIENT CHARACTERISTICS BY HOSPITAL VOLUME AND YEAR

	Hospital Volume			
	1	2 or 3	4–9	10+
In-hospital death, %				
1988–1991	14.6	13.2	8.9	4.7
1992–1995	15.9	11.1	8.2	4.3
1996–1998	9.5	11.1	9.4	3.3
Age, mean years				
1988–1991	64.2	65.3	63.2	61.2
1992–1995	63.9	64.3	63.6	62.2
1996–1998	65.1	63.9	64.1	61.9
Female, %				
1988–1991	46.8	47.6	46.3	47.2
1992–1995	42.3	45.8	48.9	45.0
1996–1998	48.8	48.3	49.1	49.4
Charlson index, mean				
1988–1991	2.6	2.7	2.8	2.9
1992–1995	3.1	3.2	2.8	3.1
1996–1998	3.1	3.2	3.1	2.8
COPD, %				
1988–1991	7.1	9.0	6.6	0.5
1992–1995	10.4	11.0	8.2	4.5
1996–1998	12.4	11.1	10.4	6.1
Diabetes w/complications, %				
1988–1991	10.1	9.3	7.4	7.8
1992–1995	11.0	11.8	13.8	13.4
1996–1998	16.1	13.7	15.6	14.9
Kidney disease, %				
1988–1991	1.2	1.1	0.6	1.0
1992–1995	1.3	1.6	0.9	1.6
1996–1998	1.2	1.1	0.5	0.4
Peripheral vascular disease, %				
1988–1991	2.2	1.2	0.6	1.0
1992–1995	2.8	1.4	1.6	2.0
1996–1998	2.9	2.1	1.7	2.0

tient characteristics by size category and time period. The in-hospital mortality rate was 14.6% for hospitals that performed one Whipple procedure in any of the years 1988 to 1991, but only 4.7% for hospitals that performed 10 or more procedures in 1 year in the same time period. By 1996 to 1998 mortality rates in these two volume categories narrowed slightly to 9.5% and 3.3% respectively.

The descriptive statistics in Table 1 suggest that higher-volume hospitals tended to operate on younger patients. The Charlson comorbidity index increased slightly over time for hospitals of all sizes, except those performing 10 or more procedures per year. In addition, the prevalence of chronic obstructive pulmonary disease was noticeably lower in the highest-volume facilities. Kidney disease is considered to be a particularly dangerous risk factor for the Whipple procedure. Although this comorbidity was relatively rare in the sample, the prevalence of kidney disease was lowest for the highest-volume hospitals in both the first and last time periods in Table 1. These differences in case mix by hospital volume highlight the importance of analyzing the volume–outcome relation controlling for variation in patient case mix in a multivariate regression framework.

Table 2 contains results from a logistic regression model used to examine the relation between inpatient mortality and both hospital volume and experience after adjustment for patient characteristics. The odds ratios indicate that patients in hospitals performing four to nine Whipple procedures per year had a significantly lower mortality rate than patients treated in hospitals that performed only one procedure per year (OR = 0.70, $P = .01$). The odds ratio for patients treated in hospitals performing 10+ procedures per year was even lower (OR = 0.34, $P < .001$). In addition to procedure volume, the number of years of experience that a hospital had in performing pancreaticoduodenectomies was also independently associated with a lower probability of inpatient mortality (OR = 0.94, $P = .001$).

The logistic results indicate no significant difference in inpatient mortality between male and female patients. However, patients 60 years of age and older were at increased risk of in-hospital death versus younger patients. Moreover, the 95% confidence intervals for patients 70 to 79 and 80+ did not overlap the confidence interval for patients ages 60 to 69. Therefore, patients ages 70 and older were at even higher risk of in-hospital death relative to those ages 60 to 69. Patients with chronic obstructive pulmonary disease, kidney disease, and liver disease also had higher odds ratios for inpatient mortality relative to patients without these comorbidities. Mild to moderate diabetes appears to lower the odds ratio for inpatient mortality. This result is not clinically plausible, but it is consistent with past studies that suggest that administrative databases underreport chronic conditions for patients with life-threatening disorders.[16,17]

Estimates from the logistic model were used to predict the magnitude of differences in outcomes by hospital volume category and hospital experience, controlling for patient characteristics. Predictions varying with both hospital volume and experience are reported in Table 3. Ninety-five percent confidence intervals for each prediction are reported in parentheses. For example, if all patients treated in 1998 had been treated in a hospital that performed one procedure that year but had 7 total years of experience, they would have a mean inpatient mortality rate of 11.3% (CI 8.3–15.4).

If all patients who underwent a Whipple procedure in 1998 had surgery in a hospital performing the procedure for its first and only time that year, the predicted inpatient mortality rate would be 15.3%, substantially higher than the observed sample mean of 9.5%. As the figures in Table 3 indicate, predicted inpatient mortality rates fall with both increasing hospital volume and rising years of experience. Thus, greater experience appears to mitigate some of the disadvantages of treatment at a lower-volume hospital. For example, among facilities with 7 or 11 years of experience, inpatient mortality rates for medium-volume hospitals were not significantly lower than for very-low-volume and low-volume hospitals. Likewise, predicted inpatient mortality rates for medium- and high-volume hospitals with 7 or 11

Table 2. LOGISTIC REGRESSION ESTIMATES OF DETERMINANTS OF INPATIENT MORTALITY

Variable	Odds Ratio	95% Conf. Int.	*P* Value
Hospital volume (procedures/yr relative to 1/yr)			
2 or 3	0.84	(0.66–1.08)	.18
4–9	0.70	(0.53–0.93)	.01
10+	0.34	(0.20–0.56)	<.001
Experience (years)	0.94	(0.91–0.98)	.001
Age (relative to <60)			
60–69	1.86	(1.40–2.47)	<.001
70–79	3.42	(2.61–4.50)	<.001
80+	4.76	(3.41–6.66)	<.001
Female	0.86	(0.72–1.03)	.11
Charlson comorbidities			
Chronic obstructive pulmonary disease	1.50	(1.15–1.96)	.003
Diabetes (mild/moderate)	0.54	(0.40–0.74)	<.001
Diabetes w/complications	0.90	(0.56–1.44)	.66
Kidney disease	14.17	(7.15–28.08)	<.001
Liver disease (mild)	2.43	(1.31–4.50)	.005
Liver disease (moderate/severe)	4.84	(2.40–9.75)	<.001
Peripheral vascular disease	1.42	(0.80–2.50)	.23
Prior myocardial infarction	0.27	(0.06–1.24)	.09
Rheumatologic disease	1.18	(0.25–5.56)	.83

years of experience were not significantly different. Additional predictions not reported in Table 3 indicate that these findings hold true for hospitals with 8 through 10 years of experience.

Although greater experience was associated with lower inpatient mortality rates in Table 3, there were no cases in which the predicted mortality rate for hospitals with 11 years of experience was significantly lower than for a hospital with the least experience in the same volume category. For instance, although the predicted inpatient mortality rate for patients treated in a very-low-volume hospital with 11 years of experience (9.2%) was lower than for a very-low-volume hospital with 1 year of experience (15.4%), the 95% confidence intervals for the two hospital types overlap.

Moreover, high-volume hospitals with 7 years of experience had a predicted inpatient mortality rate (4.3%) that was significantly lower than that for very-low-volume and low-volume hospitals (11.3% and 9.8% respectively) with similar experience. Additional predictions not reported in Table 3 indicate that the significantly higher mortality rates for very-low-volume and low-volume hospitals versus high-volume hospitals persist for hospitals with 8, 9, or 10 years of experience. For hospitals with 11 years of experience, the predicted inpatient mortality rates for high-volume versus very-low-volume hospitals remained significantly different (3.4% vs. 9.2%), although the confidence intervals for high- and low-volume facilities overlapped. Thus, over the range of procedure volumes and years of experience observed in the data, high procedure volume rather than greater experience is associated with large, statistically significant reductions in inpatient mortality.

We estimated additional specifications that included either individual year dummy variables or indicator variables for 1992 to 1995 and 1996 to 1998 versus 1988 to 1991. In both cases these additional variables were not significant at the 95% confidence level, while experience remained pre-

Table 3. PREDICTED INPATIENT MORTALITY BY VOLUME AND EXPERIENCE BASED ON PATIENT CHARACTERISTICS IN 1998

	Experience (years)			
Volume	**1**	**4**	**7**	**11**
1	15.3 (11.7–19.9)	13.2 (10.0–17.3)	11.3 (8.3–15.4)	9.2 (6.1–13.5)
2 or 3		11.4 (8.7–15.0)	9.8 (7.3–13.1)	7.9 (5.4–11.4)
4–9			8.3 (6.1–11.4)	6.7 (4.6–9.7)
10+			4.3 (2.6–7.0)	3.4 (2.1–5.6)

95% confidence intervals are in parentheses.

cisely estimated. We also could not reject the hypothesis that interaction effects between hospital volume and experience were equal to zero. Dummy variables for indications for surgery[8] (pancreatic cancer, extrahepatic bile duct cancer, duodenal cancer, benign pancreatic disease vs. other diagnoses) were not precisely estimated and therefore were also not included in the final regression specification.

DISCUSSION

Although past studies of the Whipple procedure and pancreatic resection have tested for reductions in inpatient mortality over time,[18,19] this is the first study that explicitly tests for an association between years of hospital operating experience and inpatient mortality for pancreaticoduodenectomy. The results in this paper indicate that both increased procedure volume and increased experience are associated with lower mortality rates for patients undergoing the Whipple procedure. However, over the range of procedure volumes and years of experience observed in the data, high volume rather than experience is associated with marked reductions in inpatient mortality that are statistically significant. Predicted differences in inpatient mortality rates for hospitals in the same volume category with different years of experience are not statistically significant.

These results are consistent with the "practice makes perfect" hypothesis originally proposed by Luft et al.[20] Although increased years of experience are associated with lower mortality rates, the volume of procedures performed is more critical in achieving better outcomes. Indeed, all pancreatic resections are technically demanding and require expert surgical and anesthetic care[19] that can be achieved only through frequent repetition. Experience with treatment of complications requires the skills of diagnostic and interventional radiologists, critical care specialists, and infectious disease, nursing, and nutritional support services;[19] these also may improve only after treating several patients.

On the other hand, the results may be due to the ability of high-volume providers to offer services that low-volume facilities cannot afford. Johns Hopkins performed 271 Whipple procedures between 1988 and 1993, which enabled them to employ dedicated intensive care unit attending physicians and specialty support services.[9] The high volume of procedures also led Johns Hopkins to formulate treatment protocols and critical pathways for the Whipple procedure, as well as standardization of diagnostic workups, technical operative details, and management of the postoperative course.[18] This attention to encouraging best practices may have led to improved outcomes.

The association between higher volume and better outcomes for the Whipple procedure and all types of pancreatic resection has been used to recommend regionalization of these procedures either through minimum volume standards or referral of patients to "centers of excellence."[6,8,9,18,21–23] The results of this study strengthen this recommendation. Although hospitals with 11 years of experience performing one Whipple procedure per year have a predicted mortality rate that is lower than for very-low-volume hospitals with only 1 year of experience, the differential is not statistically significant. Moreover, very-low-volume hospitals with 11 years of experience have a predicted mortality rate that is significantly different and almost three times higher than that for hospitals with 11 years of experience that perform 10 or more Whipple procedures per year (9.2% vs. 3.4%). Thus, experience does little to mitigate the difference in mortality observed between low- and high-volume hospitals.

Predicted inpatient mortality rates for medium-volume versus high-volume hospitals with 7 years of experience were not significantly different. Similar results were found for medium-volume and high-volume hospitals with 11 years of experience. These results suggest that achieving a procedure volume of four to nine procedures per year may be sufficient for minimizing inpatient mortality. However, predicted inpatient mortality rates for hospitals performing 10 or more procedures per year with 11 years of experience were significantly lower than for medium-volume hospitals with 7 years of experience. Therefore, over the long run, higher procedure volume and experience combine to favor outcomes at high- versus medium-volume hospitals.

The results of this study also suggest that risk-adjusted inpatient mortality rates for the Whipple procedure are higher for patients ages 70 to 79 versus younger ages and even greater for patients 80 years and over. These results are in direct contrast to studies of pancreatic resection based on much smaller sample sizes (e.g., 69–727 patients) that conclude that patients 70 years of age and older have mortality rates similar to younger individuals.[24–28] Increased age has been associated with higher inpatient mortality in other studies of the Whipple procedure based on large administrative databases.[8,18] Further analyses of the relation between age and mortality should be pursued using large samples with more detailed clinical data.

There are several limitations associated with this analysis. The analysis does not control for a potential physician–volume effect for patients undergoing the Whipple procedure, because the California discharge database does not contain physician identifiers. However, past studies with physician identifiers did not find a significant independent effect of individual physician volume on hospital mortality for pancreatic resection, although the hospital volume–outcome relation persisted.[10,19,22]

The advantages and limitations of using administrative data to analyze volume–outcome relations have been discussed previously.[8,29–31] The California and Florida hospital discharge data lack information on functional status and serum albumin level, which are strong predictors of surgical mortality.[32,33] Information on tumor stage is also unavailable in the discharge data. However, a study based on data from the Surveillance, Epidemiology, and End Results database found no evidence that tumor stage varied according

to hospital volume for pancreatic and several other neoplasms.[5]

Administrative data are the only information source for which the volume–outcome relation can be examined for a large sample of hospitals over an extended time period. The data used in this study comprise all Whipple procedures in Florida and California and provide information on important variables such as age, sex, major comorbidities, and inpatient death. For this reason, most volume–outcome studies rely on administrative data.[5,6,8,9,18,19,23]

In summary, given that experience does little to mitigate the volume–outcome effect, efforts to regionalize performance of this procedure should continue.

Acknowledgment

Vivian Ho, PhD, gratefully acknowledges salary support from the Lister Hill Center for Health Policy and the Center for Aging at the University of Alabama Birmingham.

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